ASPECTS OF THE MANAGEMENT OF INLAND WATERS FOR FISHERIES

by

R.L. Welcomme and H.F. Henderson
Fishery Resources and Environment Division

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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PREPARATION OF THIS DOCUMENT

The management of inland waters for fisheries presupposes a knowledge of the potential and functions of fish stocks, as well as a familiarity with the many other uses of water and aquatic organisms. Taken together these elements can allow the incorporation of fisheries objectives into the general management planning of river basins, thus safeguarding a valuable source of protein food or relaxation. This document assembles and summarizes these elements together with the basic management techniques available. It uses mainly FAO documentation and seeks a synthesis of the work carried out by the FAO Department of Fisheries on inland waters in recent years. More detailed information on the many topics discussed are available in the material referred to.

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CONTENTS

Abstract

Inland waters are not only managed for a number of fisheries objectives but also for many industrial, agricultural and domestic purposes which affect the aquatic environment, including the fish stock. A prerequisite for correct management is the setting of objectives which take into account these various uses and which are consistent with the requirements of the fishery and the internal and external constraint upon it. A variety of management techniques are available whose applications are discussed in the text.

1. INTRODUCTION

The management of inland waters for the benefit of fisheries has interested scientists and fisheries administrators for many years. As a result of the development of methods for the biological investigation of fish species and for the statistical assessment of their stocks, the training of fishermen and the installation of fish harbours, treatment plants and marketing networks, catches of fish from inland waters have quadrupled in the last 25 years and are now nearing the estimated maxima in many areas of the world.

As the present phase of rapid expansion draws to a close the need increases for more effective management of the waters to augment production and ensure sustained yields. Furthermore, whilst fisheries have been expanding so have many other agricultural, domestic and industrial activities for which water is essential. As a result competition is arising in many sectors for what are now recognised to be limited renewable resources. Consequently, priorities for fisheries management have shifted from the narrow aim of a rapid development of a resource, to an attempt to balance fisheries needs against those of other users.

This means that decisions within the fisheries sector are frequently dictated by factors external to the fishery. It is not always possible to select the path that seems most logical in accordance with traditional approaches to fishery management. The use of the aquatic resource for one or more of the objectives associated with fisheries must be integrated into the general planning of the lake or river basin as a whole. Indeed there are circumstances which entirely preclude the use of a water body for fisheries. These do not always entail the effective destruction of fish stocks, as might happen locally in an area devoted to heavy or highly polluting industry, but might also occur in a rich and healthy water body as in the case of game or nature reserves. We will not consider such rare cases here but will concentrate on those areas where fisheries and other water uses coexist and where the resulting tensions or conflicts must be resolved. In this paper we have assumed, for the most part, that the decision as to how a particular water resource is to be used has been taken, either explicitly or implicitly, externally to the fishery. The fishery manager is, however, being asked more frequently to participate in the higher levels of decision-making, usually by providing estimates of the short and long-term values of various kinds of fishery use.

Those who make the decisions on the use of water resource are not always aware of the ways in which the components of the multi-use system react upon the fish stock or even the effects of fishery management decisions upon the fisheries. This document which has been prepared in an attempt to clarify these points, gives an outline of the various considerations bearing on the management of inland waters for fisheries, summarizes some of the ways in which they are likely to interact and discusses the various factors determining the setting of priorities within the aquatic system and the fishery.

2. EFFECTS OF PRIORITIES IN THE MULTIPLE-USE SYSTEM

Fisheries do not consume water but they do require certain conditions of water quality and environmental protection that preclude or limit many other activities. Thus whilst the use of water for recreation, for instance, does not normally interfere with the interests of the fishery, development for industry may cause serious effects. The decision whether an area is to be used primarily for fisheries, or whether fisheries is to be only a secondary consideration, therefore becomes basic to the formulation of subsequent policy.

In areas designated as primarily for fishing, all other activities must be subservient to the maintenance of an environment acceptable to the favoured stock or stocks. Protective actions may have to extend far beyond the actual zone to be managed, especially in the case of rivers where actions far upstream can influence the fate of the fish stocks elsewhere.

Where fisheries is the dominant use the fisheries scientist is far freer to exercise his craft, using traditional biological and ecological approaches to the solution of what are purely fisheries problems. But even here the objectives for which the fishery is managed arise from socio-economic considerations external to it.

If fisheries are not the priority users of the system, they may have lower priorities until in the most extreme instance they disappear through excessive pollution, or because the water body on which they depend has been converted into dry land. In such cases the fisheries manager has to maintain some sort of fish stock by compromises with other interests and his choices are even more restricted by decisions taken external to the fishery.

3. USES OF THE AQUATIC RESOURCE FOR PURPOSES OTHER THAN FISHERIES

In many ways the assemblage of characteristics of a river summarizes the geology and geography of its basin as well as its development for human affairs. By extension this applies even to large lakes, though to a lesser degree. Indeed all activities taking place on earth are eventually reflected in the waters and thereby affect the fish populations inhabiting them. This concept is of course too extensive to be of use in the management of aquatic systems and certain activities have to be identified as bearing more directly on the fish resource.

Water itself is used for a great variety of purposes other than fisheries. Some of these may consume water, in that during the process of use water is either taken from the system, or is altered in quality by the addition of extraneous materials or heat. In this category comes the use of water for drinking by humans and animals, for irrigated agriculture, for domestic purpose, and for a great variety of industrial processes including the generation of energy. Other uses may not consume water in that its quality or quantity is left relatively unchanged by the activity. Such include the use of water for ornament or for recreation, and to some extent for navigation. Actions within river basins which do not directly use water may also induce important changes in the aquatic system. Thus harvest of forest resources can alter the water regime to give shorter and more intense floods and increased silt loads. Fertiliser use can be reflected in the aquatic system as an enrichment with nitrogen and phosphorus, and insecticides sprayed on land equally tend to appear in the adjacent water ways.

Users of water may firstly alter its quality, secondly alter its quantity and thirdly produce structural changes within the aquatic environment.

3.1 Changes in Water Quality

Changes in water quality are brought about by the addition of substances to the water. These may either pollute the water or enrich it. Although pollution and enrichment (which is also called eutrophication) are usually equated it is useful to keep the two concepts separate as they can have entirely different consequences for the fish stock. Pollution arises mainly from industrial activities and has received wide attention from diverse sources in recent years giving rise to many publications on the subject (e.g., Hynes, 1971). The effects of pollution on the aquatic life in the system may be summarized as:

i. Actual lethal toxicity which kills the fish at some stage of its life history;

ii. Sub-lethal effects which may be difficult to detect or to prove, but which alter the fish's behaviour in such a manner as to prevent its completing its normal life cycle, or simply to reduce its growth;

iii. Cumulative effects which can render fish either unsafe or unpalatable for consumption.

Most pollution effects tend to be very broad affecting many different species. Whatever their immediate effect, the response at the community level is a reduction in diversity and a shift in species composition toward relatively smaller, shorter-lived forms. This tendency mimics the changes expected from heavy fishing; see section 5.4, Fig.3 (Regier and Henderson, 1973; Regier and Loftus, 1972), and the different forms tend to be additive or even synergistic. Pollution stress therefore is apt to reduce the amount of fishing which is allowable irrespective of the objectives for which the fishery is being managed.

Enrichment arises mainly from domestic or agricultural wastes which enrich the environment by the addition of phosphorus, nitrogen and organic substances. Moderate enrichment is not necessarily harmful and may even be beneficial, but heavy enrichment grades into pollution when it is sufficient to produce deoxygenated conditions in the affected body of water.

It is obviously unrealistic to assume that polluting activities can be arrested completely, but several countries categorize waters according to use and accept that only certain waters can be maintained at a quality suitable for fish (Holden and Lloyd, 1972). For example, Belgium, employs three categories: A - fit for human driking water (also useable for fish); B - fit for animal drinking water and fisheries; C - fit for industrial uses only. The quality of water in any water course may be regulated according to a set of criteria established for individual contaminants (U.S. Department of the Interior, 1969; Doudoroff and Shumway, 1970; EIFAC Working Party on Water Quality Criteria for Freshwater Fishes, 1964, 1968, 1968a, 1969, 1970, 1972, 1973, 1973a, 1973b). These criteria pertain to the requirements for fish, but other sets of criteria have been established for alternative uses of the aquatic environment (particularly for drinking water). Difficulties have been known to arise in selecting which of the particular criteria should be selected for any water body. It should be evident that management of waste disposal must be done considering the whole drainage basin so that the alleviation of problems in one place does not unintentionally intensify problems elsewhere. The mixing of persistent or toxic wastes with readily "recycled" organic materials in industrial and domestic sewerage should also be discouraged for optimal use of scarce water resources. It is particularly easy to forget that lakes are not self-contained, and while exhibiting their own individuality are also affected by the character of the inflow.

Deleterious effects on the value of water bodies need not be restricted to pollution of the water itself but extend to surrounding areas. Intensive recreational use in pick-niking, swimming and boating, for instance, may result in so much litter that property values on lake shore sites are affected and the type of fishermen interested in fishing such waters changes.

3.2 Changes in Water Quantity

Changes in water quantity may take the form of an alteration in the absolute amount of water available for fisheries or differences in the timing of release of water and the shape of the flood curve in rivers. They arise from the creation of dams and impoundments, irrigation and drainage schemes, water transfer, and the canalization and levée construction associated with flood protection. Surface run-off, and therefore the amount of water entering freshwater systems, is also incidentally increased as a result of urban construction, deforestation, road building and certain agricultural practices which produce shortened but intensified spates. Water quantity, with emphasis on river and stream discharges, has been examined by Fraser (1972, 1972a, 1975). In general, changes in water quantity can affect fisheries in two ways, firstly by modifying the environment through inadequate dilution of pollutants and secondly by acting directly on the biology of the fish (see Table I).

TABLE I

Water- and land-use development. Problems and solutions (from Dill, Kelley and Fraser, 1975)

	Development Activity	Possible Negative Effect	Possible Solution
(1a)	Dam or barrage construction	Barrier or deterrent to upstream movement of fish - especially serious with respect to migratory fish which depend upon reaching certain stream, lake or estuarine areas utilized as spawning or nursery grounds.	(i) Installation of a passage over or through the dam (e.g., fishway, fish lift or fish lock). (ii) Transportation (e.g., trucking) to a point above the barrier.
(1b)	Dam or barrage construction	Deterrent to downstream migration - especially of young migratory fish. Stream fish often cannot find their way through a large reservoir and if they do, they may find no suitable downstream escape route through or over the dam.	(i) Regulations of flow (or drawdown) to attract fish downstream. (ii) Modification of dam outlets and spillway to allow fish passage over or through the dam (coupled with provision of suitable basal pools); creation of special exits such as flumes or by-passes or modification of fishways or provision of collecting points for young fish for transfer downstream. (iii) Employment of special devices or methods (e.g., artificial currents, lights, bubbles, vibration, electricity, etc.) to direct downward migrants to safe exits. (Solution often difficult.)
(1c)	Dam or barrage	Deposition of sediments in downstream areas and turbidity during construction. Turbidity is usually temporary but the deposition of sediments in the stream bed below storage reservoirs often destroys habitat for years (see also (5)).	Recognition of the danger prior to construction. Place controls on the construction process; bind contractor legally to prevent such damage.
(1d)	Dam or barrage construction	Reduction or elimination of a salinity gradient required for upstream or downstream migration of fish or other aquatic organisms.	Preservation or creation of an alternative migratory route with an artificially created salinity gradient.

(2a)	Impoundment and/or diversion or abstraction of water	Loss of the original stream fishery within the reservoir basin. Alteration of upstream fish fauna because of migrations of fish from the reservoir.	Development of a fishery in the new reservoir (man-made lake). For example, although it is often enough to merely await the development of fishable stocks from species already resident in the impounded drainage, it may also be useful to add to or replace some of the components of the original assemblage of food and/or sport fishes (see section 6.3). Efforts may also be made to change the composition of other faunal (or floral) assemblages such as plankters, benthic invertebrates, forage or predatory fishes. Other aids to development of fish populations (listed in the tables that follow) include installation of spawning devices, improvement of shelter, vegetation control, and destratification. (see section 6.2). Fishing for food species using nets may be facilitated by clearance of trees and brush prior to impoundment. Conversely, the addition of fish attractors may be useful in improving fishing for either food or sport fish. Aside from the development of a fishery in the major reservoir which has been created, it may be possible to establish aquaculture in other areas (especially irrigated ones) using some of the water diverted from the stream (see section 6.4).
(2b)	Impoundment and/or diversion or abstraction of water	Reduction of the downstream fisherman's ability to catch fish because his traditional gear and boats are no longer adequate to cope with the changed environment or different species of fish.	Investigation of new needs, training and provision of different equipment.
(2c)	Impoundment and/or diversion or abstraction of water	Reduction of flow in normal stream channel below dam, with a consequent reduction of living space and spawning	(i) Provision of adequate flows of water, especially at critical times of year or even day.

(2c)	Impoundment and/or diversion or abstraction of water	and nursery grounds, changes in food production zones, etc. Reduction of flood flows will reduce the size of overflow areas (ditches, swamps, oxbows, etc.), and restrain lateral migration by mainstream fish into the formerly inundated areas - thus lessening total fish production through losses in recruitment and available spawning, nursery and feeding areas. Productivity in the main stream can also be lessened through diminished inflow of organic matter from the formerly inundated areas. (Such changes are particularly harsh on the "warm-water fishes" of both temperate and tropical regions.) Conversely, reduction of flow may be harmful in some streams by diminishing the normal pattern of flushing action which serves to keep channels clear for fish migration and prevents the encroachment of riparian vegetation which may diminish fish habitat and make (sport) fishing difficult. Abnormal augmentation of flow (which may also be a concomitant of water impoundment or diversion) can cause severe flushing and erosive action.	
		Fall in water level below a dam may uncover barriers to upstream movement and inhibit downstream migration of fish.	Removal of exposed barriers
(2d)	Impoundment and/or diversion or abstraction of water	Changes in velocity of water with consequent effect on holding position of fish, their feeding, spawning, etc.	As above. Installation of devices to increase or decrease velocity. (see section 6.2).

(2e)	Impoundment and/or diversion or abstraction of water	Change in water quality below dam (e.g., discharge of dissolved toxic gases or water with low oxygen) with consequent injury to fish (see also (5) below)	(i) Regulation of time, place, and amount of discharge. (ii) Destratification of the reservoir by various means, to improve water quality. (iii) Clearing of vegetation from reservoir. (iv) Re-aeration below dam.
(2f)	Impoundment and/or diversion or abstraction of water	Changes in water temperature which affect survival of particular species, or spawning, food production, etc.	Selective water release from surface or lower levels of the reservoir, through installation of multiple outlets or changes in chronology of release.
(2g)	Impoundment and/or diversion or abstraction of water	Disappearance of shrimps, oysters, and other estuarine species through changes in the seasonal salinity gradient or reduction of food supply as floods decline.	(i) Modification of the stream flow releases to accommodate various environmental requirements of the estuarine fauna. (ii) Relocation of the fishery. (May require different boats and gear.) (iii) Substitution of aquaculture of various kinds.
(2h)	Impoundment and/or diversion or abstraction of water	Fluctuation of water level in reservoir above dam. May strand fish, reduce living space, destroy vegetation, change or reduce food components, influence spawning adversely, produce changes in habits inimical to stocks, etc.	(i) Regulation of levels to provide "minimum pool", and/or more constant conditions at critical seasons. (ii) Construction of secondary impoundments. (iii) Salvage of stranded fish. (iv) Substitution of artificial vegetation or substrates (if required, say, for spawning).
(3a)	Diversion or abstraction of water from streams or reservoirs	Loss of fish which enter diversions (canals, penstocks, etc.). Physical damage to fish passing over dams.	(i) Installation of mechanical fish screens (stationary, rotary, belt-type, travelling, louver, etc.), or electrical deflectors or screens. (ii) Use of by-passes in diversions to enable fish to return to streams.
(3b)	Diversion or abstraction of water from streams or reservoirs	Transfer of unwanted fish from one drainage to another. (Mixing of stocks otherwise desirable (inter-basin transfers).	(i) As in (3a above. (ii) Elimination of unwanted fish from a stream above its diversion point, usually by use of toxicants. (Note that solutions to this problem are difficult - in fact, rarely successful. For example, fish screens are never 100 percent efficient; toxicants frequently fail to remove all the unwanted fish. The effect of possible introduction should, therefore, be carefully assessed during the planning stages.)

(4)	Drainage and dredging or land-filling of water and wetland areas (estuaries, lagoons, marshes, overflow areas, etc.) Modification of stream courses, removal of gravel, deposition of spoil, logging debris, etc.	Destruction of habitat, spawning areas, food-producing zones, etc. Creation of barriers or deterrents to fish migration.	(i) Prevent damaging drainage. (ii) Attention to preservation of natural features of streams, e.g., contours or meanders rather than straight chutes. (iii) Provision of adequate flows to maintain overflow areas. (iv) Ban on removal of gravel necessary for spawning. (v) Removal of debris. (vi) Removal of unnatural barriers. (vii) Installation of devices to permit migration (e.g., through road culverts).
(5)	Any activity resulting in water pollution	Degradation of aquatic habitat (as through silting, which destroys stream bed organisms, renders spawning gravels less permeable, etc.), destruction of food organisms, deterieration of fish stocks, changes in species composition, mass destruction, establishment of residues in fish flesh which are harmful or objectionable to consumers.	(i) Control of siltation through reforestation, cover cropping, terracing, contouring, better road location, soil stabilization, etc. (ii) Removal of silt from channels through various devices. (iii) Control of other forms of pollution by pre-treatment of effluents, timing of discharges land disposal, of pollutants, redesigning of processes to alter quality and quantity of effluents, better location of plants, re-use of wastes, etc. (iv) Ban on use of certain pollutants.
(6)	Any of the above which reduce fish stocks or habitat.	Reduction or change of habitat to such an extent that the natural wild stocks have declined to a point of almost no return.	Replacement or augmentation of fish stocks through: (i) artificial stocking; (ii) operation of artificial spawning areas. Such means may involve the construction and operation of new fish culture facilities for collection, holding, spawning, hatching, rearing, and transport. If study shows that the decline in natural stocks (due to the development project) will be severe, provision for some or all of the above measures should be an integral part of the project. If it is indicated that reliance on such measures will not be able to offer adequate replacement of the decimated stocks, then consideration should be given to other forms of compensation as an integral part of the project

3.3 Changes in the Structure of the Environment

Structural changes to the environment involve such factors as channel shape, shoreline development, bottom type and accessibility to the living organisms. The most obvious example of massive change to the environment is the construction of dams. These bar the passage of migrating fish, but also alter the flow regimes downstream drying previously inundated areas and producing major changes in the form of the river bed. Both these factors affect the plant and animal life. Upstream of dams the reservoir supports fish populations which can form the basis for new fisheries. Usually a net gain to fisheries is assumed, but in some areas, where especially productive floodplains have been lost the balance may be the reverse. Canalization, the straightening of river channels, and their containment in artificial levées produces similar effects on fish populations as those which occur downstream of dams, i.e., a simplification of species composition and an overall drop in productivity (e.g., Congdon, 1973; Holden and Stalnaker, 1975).

Increasing changes are occuring in many of the world's major rivers due to siltation caused by poor basin management. High silt loads tend first to choke existing vegetation, but later build internal deltas and braided channels, filling channels, lakes and reservoirs, and finally, by raising the river bed far above the surrounding plains, provoke extensive and catastrophic flooding.

The possible negative effects of some development activities and suggestions for their solution have been summarized by Dill, Kelley and Fraser (1975) whose summary table appears in Table I.

Many of the solutions to problems caused by other uses of the system have been developed in the north temperate zone and are therefore adapted mainly to the behaviour of fish species of that region. Such technology is not necessarily transferable. For example difficulties have already been encountered in fish passes associated with dams. These structures which are suited for fish which can swim or leap against strong currents, have been successful for salmonids in Europe and North America, but experiences with similar installations in Africa (Daget, 1960) have shown them to be unsuited to African species.

4. USES OF INLAND FISHERIES RESOURCES

4.1 Inland Resources as a Source of Food

Fish and other aquatic organisms are used either directly or indirectly for human consumption. Direct use involves either an unprocessed (fresh), frozen or processed product. Fish are usually lightly processed by salting, sun drying or smoking, but heavier processing is not uncommon. Products such as Nuoc Mam (fermented fish juice) or fish pastes, cakes and pickles are available in many parts of the world. Indirect use involves the feeding of fish, often transformed into meal, to poultry or other domestic animals.

The Yearbook of Fishery Statistics provides estimates of some 10 million tons nominal catch for the freshwaters of the world. These are broken down in Table II for the five year period 1970–74. Plotting of the nominal catches over a longer period, Fig.1, shows the growth of inland fisheries over the past 25 years. In general there has been a four-fold increase overall, resulting mainly from the increases in Asia and Africa. Catches have remained fairly constant or have declined in Europe, North America and the U.S.S.R. In 1975, the freshwater fish stocks of these continents seem to be at or near the maximum yield of their capture fisheries although further gains might occur with increasing use of aquaculture. Catches in Central and South America have increased little but have a high potential relative to the present low rate of exploitation. Increases in production can therefore be anticipated in this area of the world.

TABLE II

Nominal Catches of Freshwater Fish by Continent 1970–1974
(Yearbook of Fishery Statistics, FAO, 1975)

Continent	Catch t x 1 000					
	1970	1971	1972	1973	1974	Mean
Africa	1 301	1 328	1 359	1 384	1 411	1 356
America – North	136	130	131	147	153	139
America – South	160	144	189	180	183	171
Asia – China	4 153	4 568	(4 568)	(4 568)	(4 568)	4 485
Asia – Other	2 120	2 171	2 216	2 357	2 502	2 274
Europe	226	215	223	247	252	233
Oceania	2	3	4	2	5	3
U.S.S.R.	853	935	870	850	773	856
TOTAL	8 951	9 494	9 560	9 735	9 847	9 517

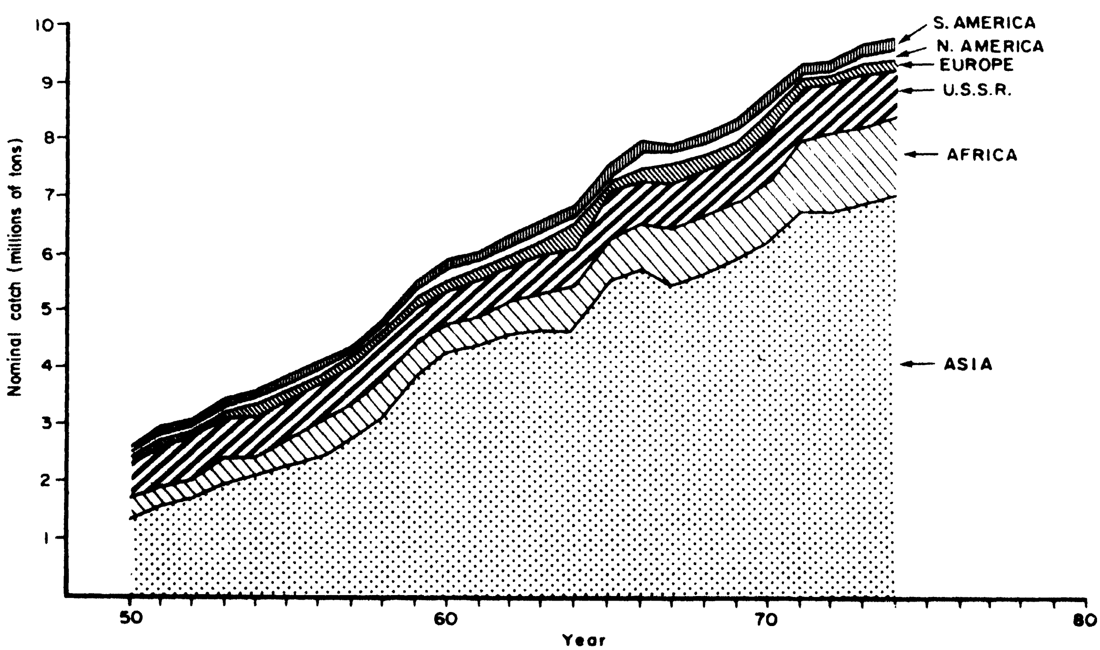


Figure 1 World Nominal catch from inland fisheries, 1970–74
(FAO Yearbook of Fishery Statistics)

4.2 Sport Fishing

The widespread use of the fish resources of inland waters for sport is a comparatively recent development and has by and large been confined to the more industrialised countries. This use of the resource is associated with what have been defined as "environmental intangibles", the evaluation of the economic and social significance of which is difficult (Coomber and Biswas, 1973; Spargo, 1972). Comparative estimates of the relative merits of sports and commercial fisheries in any one area are therefore not easy to obtain. Nevertheless, in many parts of Europe and North America, the sports fishery lobby has been sufficiently powerful to impose considerations of environmental quality as well as legislation against commercial fisheries in favour of the maintenance of a stock suitable for sport fishing.

Because of the methodological difficulties for evaluating the resource any published figures have little significance other than to give an idea of its general importance. In Table III, which shows the number of sport fishermen in various European and North American countries, the figures may apply to individuals who go fishing at least once per year (North America) or to regular licence holders as reported from other countries. Figures for sport fishermen apply to both those fishing in marine and freshwaters, but it is commonly accepted that at least two-third of these concentrate on freshwaters. Numbers of fishermen are surprisingly high and in many countries angling is classified among the major participant sports.

TABLE III

Numbers of Sport Fishermen in Europe and North America
(data from Gaudet, 1973 for Europe and from Norling 1968 for America)

Country	Number of fishermen x 1 000	% of total population	Country	Number of fishermen x 1 000	% of total population
Austria	200	2.7	Roumania	200	1.0
Belgium	230	2.4	Spain	450	1.4
Denmark	300	6.1	Sweden	1 500	18.7
Finland	750	16.0	Switzerland	250	4.0
France	5 000	10.0	U.K. (England & Wales)	2 800	5.8
Germany (R.F.)	622	1.1	Yugoslavia	158	0.8
Ireland	50	2.0	United States	25 000	12.0
Italy	850	1.6	Canada	1 311	6.0
Norway	242	6.4			
Poland	400	1.3			
			TOTAL	40 856	6.7

Gross expenditure on sport fisheries, including such items as equipment, licenses and transport to and from the fishing site, is estimated in the United Kingdom at between U.S.$400-500 million per year (Gaudet, 1973) and in Canada at about U.S.$188 million (Norling, 1968). Fees for licenses alone amount to U.S.$5 million for Italy, U.S.$2 million for Switzerland and U.S.$450 million for France (Gaudet, loc.cit.).

The amount of fish caught by sport fisheries for consumption is also quite important. Estimates range from about 20 000 to 100 000 t for France and 10 000 to 12 000 t/yr for Finland. In Belgium the 440 t caught is equivalent to 14.5 kg/ha/yr while in Poland records catch levels up to 20 kg/ha/yr. In the United States the estimate of 250 000 t from inland waters excluding the great lakes is equivalent to 29 kg/ha.

4.3 Ornamental Fish

According to recent estimates (Axelrod, 1973) the world-wide retail value of the live ornamental fish trade, including accessories, is in the region of U.S.$4 000 million per year. The majority of fish of interest to aquarists are native to the tropical and subtropical areas of the world. There are probably in excess of 6 000 species of potential interest (Lachner et al., 1970) although only about 1 000 are at present generally available. Most are small fish of no value for food, although the juveniles of some food fishes are also popular. On the whole, development of the aquatic resource to supply ornamental fish utilizes components of the community which do not conflict with either sport or food fisheries. There may, however, be ecological effects, so far undetected, resulting from the excessive exploitation of these species in their native waters and from escapement into non native waters. An idea of the scale of removal of fish is given in Table IV which indicates the relatively large numbers of fish that are withdrawn from fairly limited areas of specialized habitat.

TABLE IV

Numbers of Fish Exported from Representative Countries
(data from Conroy, 1975)

Country	Number of fish exported
Brazil	3 482 000
Colombia	10 749 000
Guyana	886 124
Hong Kong	20 398 000
Malaysia	4 329 000
Peru	15 743 000
Venezuela	10 237 000

Excluding Hong Kong, whose production is almost entirely from artificial rearing, some 45 million fish are exported from six countries. As mortalities between capture and export are in the range of 50 to 70 percent this means that at least 90 million fish are captured yearly in these countries alone.

The main countries exporting ornamental fish are:

Asia:	Hong Kong, Thailand, Singapore, Taiwan, Philippines, Malaysia, Indonesia, Japan, Laos, Korea
Latin America:	Peru, Colombia, Brazil, Guyana, Venezuela
Africa:	Nigeria, Malawi, Burundi, Zaïre
Europe:	Belgium, Federal Republic of Germany

Apart from the European countries, Hong Kong, Singapore, and Taiwan, where fish are mostly imported from elsewhere and reared or artificially bred in captivity, these exports represent fish captured in the wild.

4.4 Minor Uses

In addition to the above three uses, fish are employed for several secondary purposes. Of these two, vector control of carriers of diseases and the control of aquatic vegetation are fairly common.

Control of carriers of diseases

A locally significant use of fish is in the control of vectors of diseases organisms. Two species especially, *Gambusia affinis* and *Lebistes reticulatus*, have been widely distributed around the world to control larvae of the mosquito vectors of malaria (Zeisler, In press). To a lesser degree several species of mollusc-eating African cichlids, principal among which is *Astatoreochromis alluaudi*, have been transplanted in an attempt to control the snail hosts of schistosoma, the causative organism of bilharzia. The extent to which these fishes have been effective is difficult to assess. Eradication of the disease is almost certainly impossible by this type of biological control, but it would appear that both groups have met with some success in reducing vector numbers. In any case, in areas where intensive spraying with chemical control agents is not practicable, few alternatives to the biological approach exist. For this reason these methods are particularly popular in aquaculture or in areas where large fisheries exist.

Control of aquatic vegetation

Certain species of herbivorous fishes have been transplanted in attempts to control submerged aquatic vegetation. Chief among these in tropical areas are the plant-eating *Tilapia zillii* and *T. rendalli* and in more temperate zones the grass carp *Ctenopharyngodon idella* has been favoured. Such experiments, however, have met with variable success due to the rather unpredictable dietary habits of these species and the need for high stocking densities to obtain satisfactory results (Bardach *et al.*, 1972).

5. MANAGEMENT FOR FISHERIES OBJECTIVES

5.1 Setting of Objectives and Strategy for Management

Management for fisheries objectives is here taken to mean those actions which derive from decisions related to the fish stock or to the users of the stock. Management objectives for fisheries are usually associated with types of use (section 4) as well as with socio-economic factors connected with the fishing community. Apart from financial goals, which underlie most management practice, a typical, but not exhaustive, list of such objectives is as follows:

Objectives associated with category of use:

a) Production of food

b) Maintenance of stocks for sports fishing

c) Supply of ornamental fish

d) Control of unwanted organisms (disease vectors, vegetation, rice borers, etc.)

Objectives associated with socio-economic factors:

a) Employment

b) Conservation or other aesthetic values

Waters can be managed for one or more of these objectives and by using different species for different uses conflicts can usually be avoided. However, in intensive situations, where similar species are exploited for a variety of purposes, pressures either from within the fishery or from outside force the balance in favour of one or two only. Thus, sports fisheries have repeatedly secured legislation against commercial fishing practices in Europe and North America whereas in tropical countries heavy fisheries for food usually suppress the larger individuals and the larger species attractive to the angler.

Each category can be further divided depending on the local demands. Food fisheries, as we shall see, can be managed for a few preferred species, for maximum production of fish flesh irrespective of its type or for some mix of these. The management of sports fishing waters for salmonids or coarse fish has likewise been a bone of contention in many areas. Similarly amongst socio-economic objectives that of employment has long given rise to misunderstanding. The desire is commonly expressed that the maximum number of fishermen be employed, and at the same time that the fishermen individually derive the maximum benefit from the fishery. Such sub-objectives usually resolve themselves into quality versus quantity alternatives that seem for the most part mutually exclusive, although compromises almost always have to be made eventually and in situations of intensive use the solution is usually imposed by force of circumstances. For instance, the enrichment of many north temperate waters with nutrients from waste disposal has altered fish stocks to favour coarse fish species, often despite wishes to the contrary.

Bad management practices can also provoke conflicts between objectives where none need exist. Fishing for small ornamental fish can possibly damage stocks of food species by extensive removal of their juveniles, or intensive employment of fishermen can cause fishing pressures to rise beyond the level that can be supported by larger, more desirable species. Conversely maximum wages for individual fishermen can only be achieved where few fishermen are employed. Defining such points of tension so as to avoid such difficulties is one of the basic tasks of the fishery manager.

Among the factors which have to be taken into account when defining the objectives is that of timing of harvest. Although most fishery models assume a fairly steady demand over the year, this is not always the case, nor is it always practical on sociological or biological grounds. Many fisheries, for example, those of floodplains or for anadromous species, are fixed in time by the behaviour of the aquatic system or of the fish themselves. In other instances the fish may be required to fill a dietary lack at a certain time of the year, to conform with religious feast days or to be available for the heavy pressure of a summer sport fishing season.

In terms of management, all objectives demand action aimed at the maintenance of the fish stock and define both the preferred composition and the minimum level consistent with continued exploitation. However, management of inland fisheries is still far from an exact science. The inland fishery manager must make decisions where even a few percent change in the production of the fishery can be significant to the people engaged in it, but predictions of changes in the resources available can rarely be made within 50 percent. Evaluation of the results of any management policy on the fish stocks may also be difficult and may only be possible where relatively controlled changes are made. The greatest precision is most likely to be attained in measuring the inputs and outputs of the fishery, either in material or money, hence the effectiveness of management should usually be evaluated in such terms. Research on limnology, fish biology and stock dynamics is certainly required to further develop the principles upon which management decisions are made, but for many bodies of water such work cannot be an integral part of the decision-making process owing to its excessive cost and long-term nature. Often it is more practical to select somewhat arbitrary

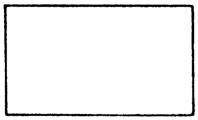
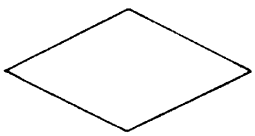
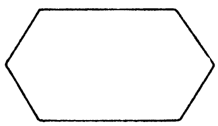
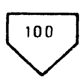
SYMBOL	SIGNIFICANCE
	FISHERY DATA GATHERING AND ANALYSIS ACTIVITIES
	DATA GATHERING AND ANALYSIS ACTIVITIES IN COMPLEMENTARY FIELDS (E.G. SOCIOLOGY, ECONOMICS)
	IMPLEMENTATION OF RECOMMENDATIONS DERIVED FROM PROGRAMME
	A DECISION BRANCH BASED ON PROGRAMME FINDINGS
	A DECISION BRANCH REQUIRING POLICY CONSIDERATIONS OR INTERDISCIPLINARY EVALUATION
	IDENTIFICATION NUMBER FOR ACTIVITY IMMEDIATELY FOLLOWING
	NEXT ACTIVITY AT NUMBER GIVEN

Figure 2 Flow chart of decisions in management of fisheries

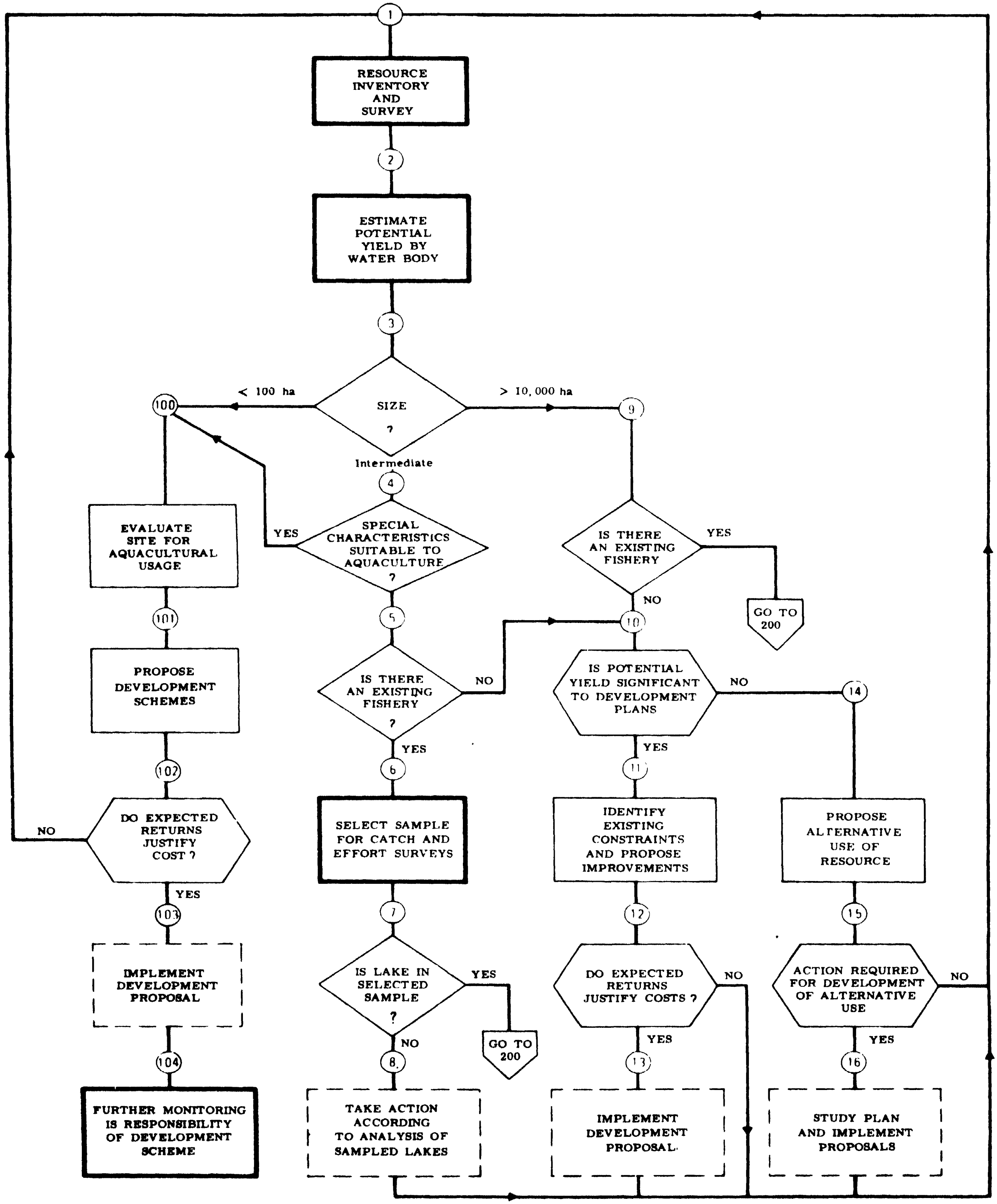


Figure 2a Flow chart of decisions in management of fisheries

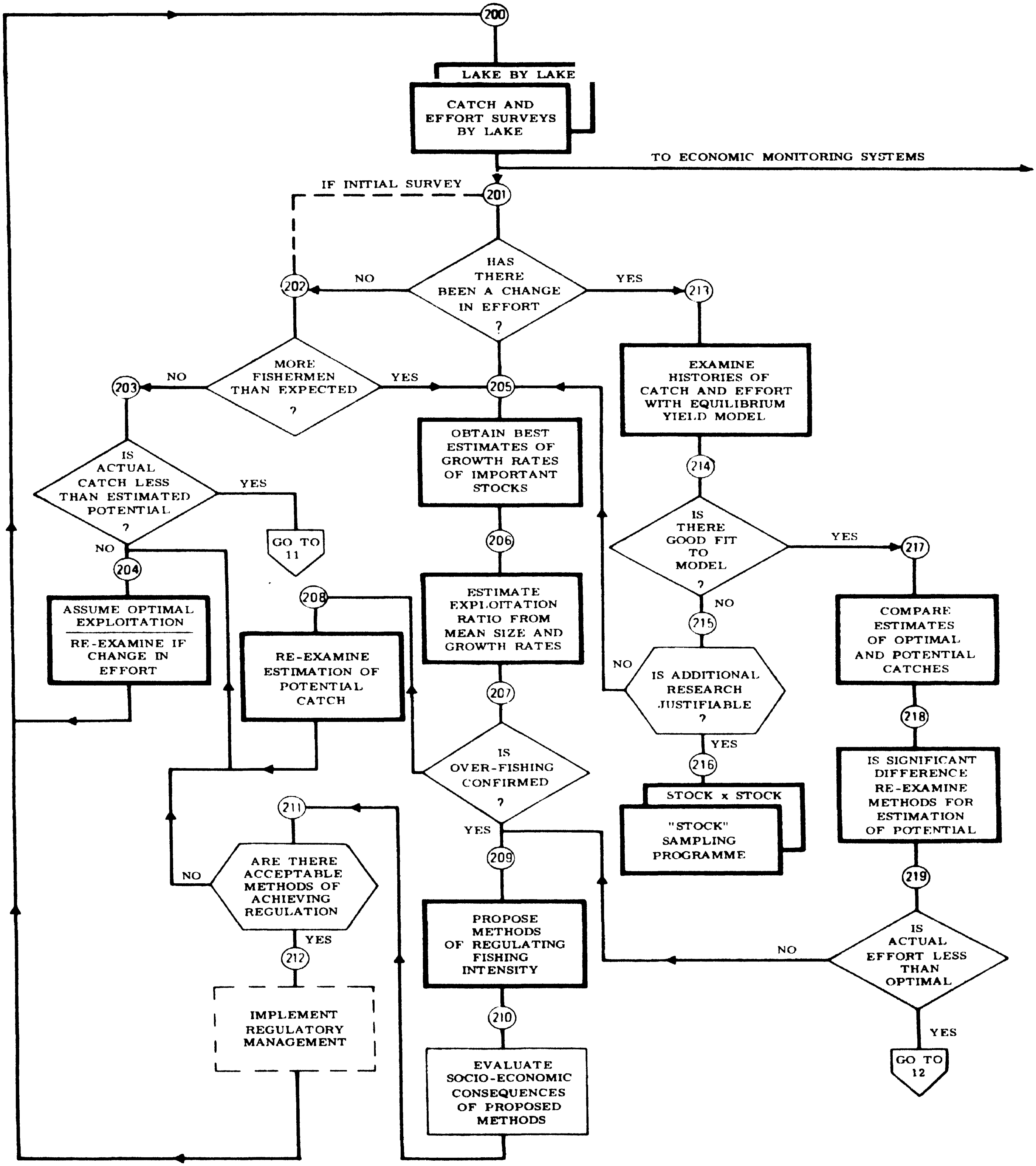


Figure 2b Flow chart of decisions in management of fisheries

management measures based on knowledge of the behaviour of other fisheries and subsequently to monitor their effects in order to evaluate the need for continuation.

This strategy for management is indeed very common. Unfortunately there have been too few compilations of the experiences of fishery managers with such decision-making. Thus there is no objective confirmation that the experiences in one fishery can be readily generalized to another.

Where there are relatively few stocks upon which the fishery is highly dependent, these stocks may fluctuate considerably in abundance from year to year. Management's greatest concern is then likely to be with the variability itself, making sure that the fishery does not move from crisis to crisis, or that it does not intensify the fluctuations (Regier, Applegate and Ryder, 1969). One possible approach to stabilization of these variations is regular stocking even if such stocking does not increase the average annual yield. (see section 6.3). Planning should at least take the element of chance into account, allowing for the bad year or occasional near complete failure.

If such probabilistic approaches are to be effective, risks must be spread over many independent enterprises. As different waters in the same locality or different fisheries in the same (large) water body may not have independently fluctuating stocks, either such risks must be spread to national or even international levels, or fishery risks must be shared with agricultural enterprises and other local sources of income. It may even be better strategy to think of insurance schemes rather than regulatory measures in such instances. Unfortunately there has been little experience in fishery science with these types of management problems.

An illustration of how a systematic strategy for efficient development and management of fresh water resources can be formulated is the plan proposed to the government of Mexico by Henderson (1974). First an inventory of all lakes, ponds and reservoirs is drawn up along with simple estimates of their potential fishery productivity. Then all these water bodies are rapidly divided into: i) those that are clearly best developed and managed as capture fisheries, (ii) those that are of mostly local interest but may have significant potential for intensive fish culture or other special uses; and (iii) those of intermediate size and potential yield. This third group consists of fisheries or potential fisheries, which are likely to be too small to warrant the permanent research programmes needed for conventional management, but are of sufficient importance that they cannot be ignored. This group can be sub-stratified with respect to such characteristics as geographical region, presence or absence of a fishery, distance from major markets and potential productivity. Using rigorous sampling methods, two or three sample fisheries are selected for intensive study. Management decisions for the whole population of fisheries could then be taken based on the behaviour of the sampled fraction.

The sequence of decisions and the information needed to make them are sketched in the two flow charts given in Figs.2a and 2b. These decision processes, which are discussed individually in more detail in the rest of this publication, are considerably oversimplified in these charts. Nevertheless, they indicate how difficult it would be to establish a completely objective and scientific management programme for the inland waters of most countries. Efficient means of dividing a large number of unit fisheries into those that do not need close attention and those that do, are clearly important tools for the inland fishery planner.

5.2 Sustainable Yield Concepts

The concept of maximum sustainable yield (MSY) has been cited for many years as a major management objective in food fisheries, and a great amount of attention has been paid to methodologies for deriving MSY for various marine and freshwater stocks. Unfortunately the concept is applicable mainly to single stocks whose abundance is relatively unaffected by a changing environment. The MSY of a stock is also sensitive to changes in the pattern of fishing on it. Outside of a few major lakes such conditions are hardly representative of

freshwater systems and MSY has been used successfully in very few cases. The use of the concept as a sole management objective also suffers from severe economic weaknesses in that the balance between long-term and short-term interests is not taken into account, a heavy bias being introduced towards the long-term situation.

To compensate for some of these deficiencies a further concept, that of Maximum Economic Yield (MEY - defined as the maximum difference between the value of the catch and the cost of catching it) was introduced. The principal disadvantage of MEY is that few fisheries, and especially those artisanal or subsistence fisheries of tropical inland waters, can be valued in purely economic terms. Furthermore conditions of cost are liable to fluctuate widely in multi-species fisheries where catch composition is unstable.

A third concept, (see Roedel, 1975), is that of Optimum Sustainable Yield (OSY) which implies the management of the fishery in terms of some particular benefit defined by the society. In actual fact, in many fisheries where maximum production of food over a prolonged period is the objective of the fishery OSY can be equated with MSY.

The optimal yield will vary not only with changes in the resource, but also with changes in social and economic conditions in the community served by the fishery. Especially in artisanal fisheries where the individual has other non-fishery activities in his annual cycle. Indeed the optimal yield and effort may vary considerably from month to month and year to year, a factor which is usually more appreciated by fishermen than by fishery managers. Individual stocks often show large differences in abundance between years. However, if the fishery is diverse, as for example in most of the food fisheries of lakes and rivers, the variation in total abundance of all fishable species, and indeed the catch, is much less.

The maximum sustainable yield in weight of fish from multiple-species fisheries appears to be attainable over a broad range of fishing effort and environmental conditions. While the classic catch and effort curve is probably followed by individual components of the community, successive replacement by smaller species delays the eventual diminution of catch from the fishery as a whole. As a result the catch is made up of quite different species at different fishing intensities, although the absolute tonnage caught may remain relatively unchanged (see section 5.4). The optimal fishing intensity may occur over a much narrower range of conditions if objectives other than maximal yield are important. For instance if the larger components of the stock are preferred a lower tonnage may have to be accepted.

5.3 Assessment of the Fisheries Resource

Assessment of fishery resources has two main phases: i) the initial evaluation of a stock or fishery aimed at determining its approximate potential magnitude and (ii) the monitoring of the resource to gauge the effects of fishing practices and management measures. A number of approaches have been used for both phases of assessment.

Population dynamics: Population dynamics theory, as summarized by Ricker (1975) seeks to establish directly both the sustainable yield and the management measures required to achieve it. The methodology and literature associated with this and associated approaches is extensive and familiar and it has been successfully applied to many individual stocks. However, the studies on fish biology which provide the basic data for the necessary mathematical analysis are expensive both in terms of qualified labour and of equipment, and the advice is not always available at the time it is needed. Further, much of the theory is based on the assumption that there is time for the population characteristics of a stock to reach a new equilibrium after each change, an assumption that is almost never strictly applicable and often not even approximately so. The study of the dynamics of the stock also rapidly becomes impossible when dealing with large numbers of species (often in excess of a hundred) whose individual dynamics are likely to interact in unpredictable ways. This does not deny the usefulness of classic stock assessment as applied to single species whose commercial value and scale of capture is sufficient to justify the expense of a resource study of this nature.

Biological parameters: Simple studies on the biology of fish species while academically rewarding, do not *per se* lead towards an evaluation of the fish stock as a whole. Individual parameters have to be carefully selected either for analysis by population dynamic techniques or for monitoring. A variety of characters have been used for the latter purpose but of these, growth rate, condition factor and maturation size appear useful for providing a general indication of the health of a stock and its degree of exploitation. The Dutch, for example, regulate their rates of stocking for maintenance of sport fisheries by comparison of growth rates of a sample against a standard established from long experience (EIFAC, 1972). Similarly low condition factor or stunting may be indicative of overcrowding and underfishing or poor environmental conditions in small lakes and streams.

Catch assessment surveys: Another approach relies on judging the condition of the stocks and of the fishery from changes in catch in relation to fishing effort. The required data can be obtained by census of fishermen and landings or more efficiently by sampling surveys. Methodologies for catch assessment surveys have been elaborated by Bazigos (1974), and these provide a valuable cross check on estimates of catch arrived at by other methods. More useful as a monitoring technique than as an indicator of potential, catch assessment does provide valuable insights into the trend of the fishery itself. Unfortunately such trends arise not only from the biological component of the stock but also from the many social and economic pressures acting on the fishery. In any eventuality a knowledge of the actual amount of fish being caught is essential to any fishery and programmes of this type are indispensable to the fisheries manager.

Methods for rapid assessment: In inland waters as well as some marine environments the maximum yield to be obtained from any body of water tends to be a function of the "richness" or biological potential of the water body rather than of any particular element of its stock.

Estimates based on biological potential have the advantage that they are somewhat more rapid, if more approximate, than those obtained by careful analysis of the dynamics of the stock itself.

The relationship between fish production and a measure of biological potential has been the concern of limnologists from the early days of the science. Two factors have emerged as particularly significant. Rawson (1952 and 1955) has shown an inverse relationship to exist between mean depth and fish production in large Canadian lakes, and Fryer and Iles (1972) have demonstrated a similar relationship for African waters. The relationship between water chemistry and fishes production was investigated by Moyle (1956) for lakes in Minnesota, and the correlation between physical and chemical indices of production and standing crop of bottom fauna and fish in British Colombian lakes has been described by Northcote and Larkin (1956). These separate morphological and chemical indices have been combined by Ryder (1965) to form a morpho-edaphic index (MEI) derived from the expression:

$$\text{MEI} = \frac{\text{TDS}}{\bar{d}}$$

where TDS = Total dissolved solids or some correlate of it and $\bar{d}$ = mean depth. The use of this index has been further elaborated by Jenkins (1968 and 1970), Henderson and Welcomme (1974) and Ryder *et al.*, (1974). The regression lines Catch = $14.3136\text{MEI}^{0.4681}$ obtained for African lakes by Henderson and Welcomme and Catch = $2.094\text{MEI}^{0.4461}$ for north temperate Canadian lakes by Ryder (1965) have similar slopes. They are, however, parallel with catch values of the north temperate series being about one tenth those of the African series. This suggests a third factor of importance related to climate, as yields of tropical lakes as a class appear to be considerably higher than those of north temperate regions. MEI is now used as a management tool in Canada and the United States, and has proved of wide application for the rapid assessment of potential in Africa and South America.

Similar approaches to the evaluation of stocks in rivers have proved more elusive. However, it has been shown that for African systems at least, fish catch is primarily a function of river length (approximately $c = \frac{L^2}{300}$), but also varies according to the degree

of floodplain development and the conductivity of the water (Welcomme, 1976).

Such rule of thumb approaches to the assessment of the mean long-term production to be expected from inland waters are generally of insufficient precision to permit the drawing up of legislation oriented toward fisheries for particular species. For these, more precise studies based on biological parameters of the fish themselves are necessary. What the broad estimates do give is a general idea of the magnitude of the resource for the judgment of the general size of investment whether in roads, research, treatment installations, etc., as well as the significance of the fishery in the general economy of the river or lake basin. They also give a rapid approximation of the number of fishermen that the fishery can support.

While the biological productivity of the resource is a key element in determining the value of a particular fishery, other factors such as accessibility by road and rail, proximity to markets or human population centres, and natural aesthetic beauty must also be considered, as these also affect the viability of market or sport fisheries. Demand factors are also significant. In regions which are richly supplied with lakes and rivers and where population density is low few conflicts are apt to arise, whereas in densely populated and highly developed areas there is a great pressure on water use. A relatively simple inventory taking into account such characteristics of the water bodies in the region for which a fishery manager is responsible can give him the perspective needed to give rational advice on priorities of usage.

Recently, the development of acoustic methods for the assessment of standing stocks of fish presents another possibility for rapid assessment. So far confined in its application to pelagic stocks from deep lakes, technological advances in the field promise well for the future extension of the methods used to other areas.

5.4 Problems of Multi-species Fisheries

A full utilization of the biological productivity of a body of water can, apparently, only be had through harvesting a variety of species each dependent on different components of the biological system. On the other hand, it is not efficient to harvest every species and there is some advantage in using only those that are relatively easy to catch but which are also collectors and consumers of components that are less efficiently captured. The choice of species to be harvested may often be based on other grounds than maximum yield of fish as when sport fish are important in the water in question. Heavy utilization may effectively eliminate larger species leaving those that are smaller, faster growing and usually more efficient converters of primary production. The kind and amount of harvesting to be done must be related to the overall objectives of use of that water body. In the usual instance both the quantity and the quality of the harvest will be important.

Figure 3 illustrates the changes to be expected in a multi-species fishery subjected to increasing intensity of fishing, where fishing intensity means the fraction of the ichthyomass removed per unit time. Initially, fishing will tend to reduce the average age of the stocks fished, increasing the efficiency of utilization of their food. Acceleration in growth rate and a reduction in the size of maturation of the exploited species is also common. Subsequently, as fishing is further intensified, the larger, slower growing, longer lived species are apt to be replaced with species of higher turnover rate. While this may also raise the productivity somewhat, through more rapid recycling of nutrients, the nutrients locked up in the fish stocks are never a very significant portion of the total nutrient pool. More importantly, as more of the predators are removed relative to the planktonic and benthic feeders, the overall food chain efficiency may be expected to improve but not as much as is often assumed (Regier and Henderson, 1973; Dickie, 1975). However, eventually one may suppose that the production normally channelled through the fish community will find its way to other parts of the system as the limits of the adaptation of fishes to high removal rates are reached. At this point the production of the fish community will drop rather rapidly.

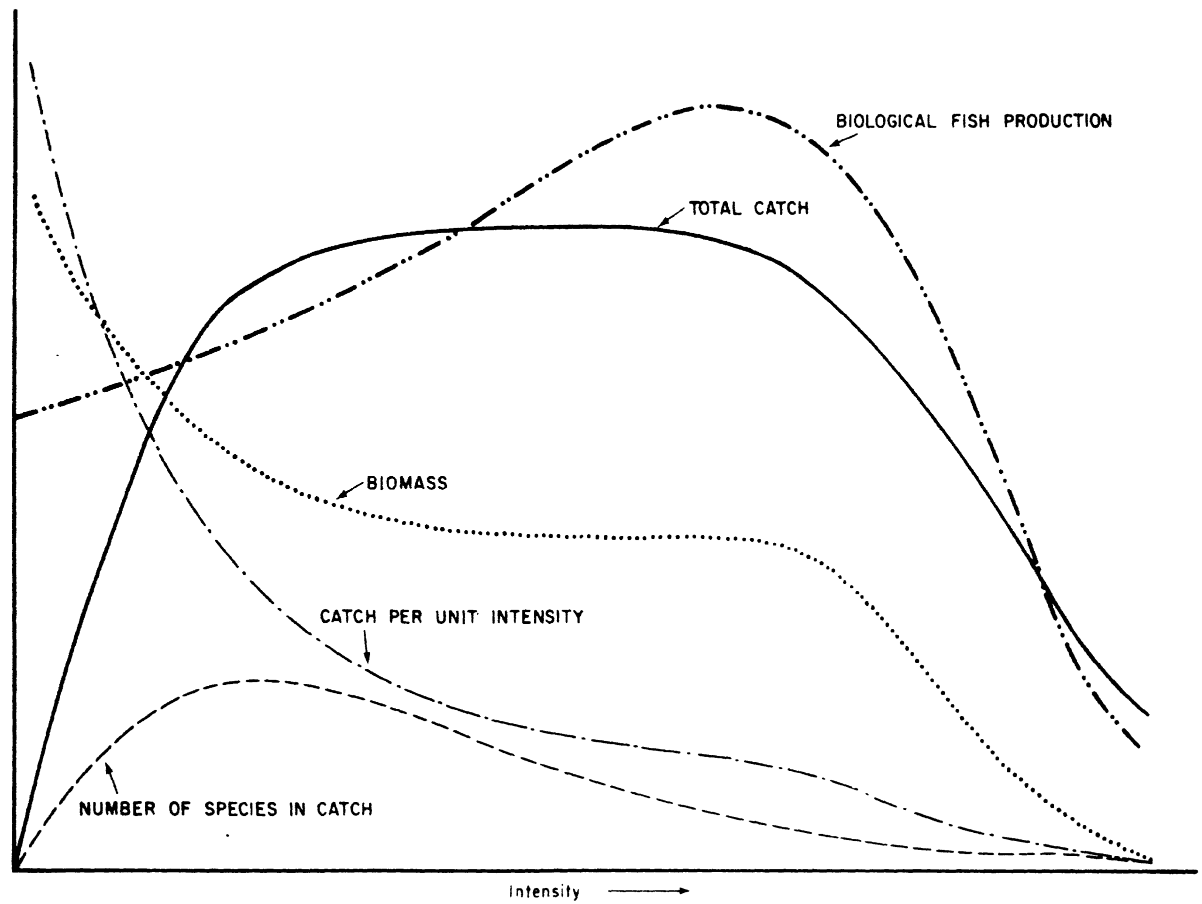


Figure 3 Diagram of changes in multi-species fishery brought about by increasing intensity of fishing

During that period when biological fish production changes rather little with increasing exploitation, the ichthyomass (biomass of fish) will tend to remain the same or even decrease as the species composition shifts to species with higher turnover rates. With decreasing biomass and higher turnover, higher exploitation rates can maintain catches, even allowing increases if the biomass does not decline too rapidly (productivity increasing). Eventually, however, the catch will also fall.

Throughout a history of gradually increasing fishing intensity, the catch per unit of fishing intensity will probably diminish. If, however, there are technological changes which result in more efficient capture, in the sense of an increased fraction of the stock removed for a given fishing effort, catch/individual effort and economic return for a unit of effort could increase while the overall catches remain constant, though the number of fishermen would have to decrease at the same time.

The number of species which make up the catch will intially increase, perhaps as shown or perhaps more slowly. In some regions, market preferences may be very restricted, so that only a few stocks will be fished. When these are reduced, it may take some time before the markets can be reoriented to replacement species. Until this happens catches may fall and fishing initially be reduced. Whether or not the original stocks recover may depend on what other stresses (e.g., pollution) are also acting on the fish community (Regier and Loftus, 1972). On the other hand the market demand may be highly diverse, as it is in many countries of Africa. In this case the number of species in the catch will first rise rapidly, much as shown, and then diminish slowly as the more susceptible forms succumb to fishing and other pressures.

6. TECHNIQUES FOR MANAGEMENT

The fisheries manager has a variety of techniques at his disposal to enable him to fulfil established objectives. These include:

i. Legislation which is aimed at the control of water quality, or of fishing practices including the setting up of fish reserves and reference areas;

ii. Stocking waters to improve the quality or quantity of the natural population;

iii. Introduction of new elements to the community to improve the stock or to fill a vacant niche;

iv. Modification or protection of the physical structure of the environment;

v. Culturing fish and other organisms under more or less controlled conditions;

vi. Influencing the social economic and political environment of the fishery.

6.1 Fishery Legislation

One of the most important and widespread of tools for the management of fisheries is that of legislation. However, to be effective laws for the control of the fishery should be based on adequate studies of the ecology of the stocks concerned. Furthermore, there should be reasonable certainty that the legislation can be enforced, a some times impossible task given the extensive, dispersed and isolated nature of some aquatic systems. Most fisheries legislation is designed to affect the fishery directly, although it is becoming more and more obvious that laws passed in domains other than fisheries may also have far reaching consequences for the waters or the fish stocks in them. Thus it is by strict legislation on effluent discharge that water quality in some European rivers has been sufficiently improved so as to once again support fish life. Similarly measures to protect forested areas in the river basin which by their control of runoff and hence flooding, may well do

more for the fish stock than any move to control the mesh size of the fishing gear used there.

Legislation aimed at the fishery itself usually attempts to control either the type of gear in use or some feature of it, or to restrict the fishery in time or in place.

Restriction or complete outlawing of the more destructive fishing practices is of course of prime importance. However, even such methods may be appropriate to some circumstances. Poisoning of water courses, for example, is liable to be damaging to the stocks of fish in rivers or lakes, whereas its use for removing fish from temporary floodplain pools, may be quite permissible. Unfortunately, were the use of poisons to be allowed in the particular case it would rapidly extend to other areas of the system. Gear is often prohibited for reasons other than those bearing directly on the fish stock. Long lines, for instance are regarded with disfavour by users of cast nets which may be snagged on the long lines, and are apt to be outlawed where the latter gear is in common use. Barriers which completely block the river channel, thus stopping fish migration are as likely to be removed for reasons of navigation as for fisheries.

Limitation of the selectivity characteristics of gear is also a widespread practice. Unfortunately much of the theory underlying mesh selection by size in gill nets has recently been shown to have somewhat dubious foundations (Hamley, 1975). Selection for size is also subject to much the same limitations as the maximum sustainable yield concept of population dynamics theory (see section 5.2) in that it only has meaning when applied to a particular species under relatively stable environmental circumstances. The motive underlying mesh size regulations is mostly for the protection of immature fish or for the adjustment of the maximum yield per recruit of the larger and more desirable species. While this is a valid objective in certain fisheries and is an effective means of managing the fishery for quality, smaller and often more abundant species are excluded from the catch and quantity considerations suffer. Usually where there is a premium on the maximum catch in a multi-species stock regardless of the species mesh sizes show a progressive trend downwards despite the efforts of the law enforcers.

Closed seasons or prohibited areas are also very common devices for the protection of fish stocks. These are mostly aimed at allowing the fish freedom to complete its reproductive cycle unhindered. Unfortunately as many fisheries are based on the concentration or passage of fish for breeding purposes, such moves are apt to be unpopular with the fishermen. Indeed, many species cannot be easily captured at times other than these and there is a tendency to allow such fisheries to persist with the resulting real loss of several species (Labeo victorianus in Lake Victoria, for instance).

A specialized case of regulation by space is that of fish reserves. Though there are few records of extinction of fish species resulting from fishing, many fisheries for individual species have collapsed from this cause. Such danger exists in some lakes such as Lakes Victoria and Malawi, where industrial trawling for multiple-species cichlid stocks must lead to severe overfishing of some species if others are to be harvested at optimal levels. While the risk of such extinctions cannot be estimated, some attention should perhaps be given to methods of protecting rare species where possible, e.g., to establish fish reserves within which fishing is prohibited. This allows the rarer stocks an opportunity to maintain, at least locally, normal densities. Similarly, in floodplain areas where flood control, drainage or other schemes are being introduced, the setting aside of areas where "normal" flooding can persist is essential to the continued survival of many species of fish which spawn in such habitats. There is an important additional advantage. Such reserve areas provide base-line data with which to judge the effects of fishing against unfished regions.

In the overall strategy of fishery development, each country or dominion should consider setting aside a small fraction of its lakes and streams as reserves, again for the primary purpose of comparison of "natural" stocks against those that are subject to exploitation.

In this connexion, however, we would emphasize that wholly "natural" systems no longer exist. For base-line purposes, it is more important that the water bodies used for reference not be subject to the changing pressures of man's utilization, either gradual or rapid. An international effort, Project Aqua, to provide for varying degrees of conservation of aquatic resources is being promoted by the International Biological Programme and Unesco (Luther and Rzoska, 1971).

A further type of legislation operates at the level of the fishermen. Often this is intended to increase the number of fishermen that may be supported by a fishery, as in the case of certain types of quota systems or licencing. As an extension of this, as pressure has grown on many of the inland waters, traditional migration patterns have been stopped, and the free passage of fishermen from foreign countries has been terminated to protect local populations. Similarly, new and more efficient techniques of fishing could readily displace large number of established artisanal fishermen. In fisheries, where employment is a major objective, restriction of a new technique is often desirable. Thus on Lake Victoria the fishing grounds of the developing trawler fishery should be confined to the deeper waters to protect the populous artisanal sector which exploits the shallow inshore waters. In a lot of cases it is probably more effective to control the number of fishermen operating on a water body than to control the type or specifications of the gear they use.

6.2 Environmental Engineering

While fisheries management is commonly understood to be concerned with regulating the amount and kind of fishing, other approaches have been attempted with differing degrees of success. Apart from stocking (see section 6.3), aquaculture (see section 6.4) and community development (see section 6.5), most of these interventions fall under a heading that might loosely qualify as environmental engineering.

Such activities may be purely biological, for instance in the case of selective poisoning of small lakes and streams to remove undesirable species or elements of the stock (Lennon et al., 1971). As an example of this type of management great increases in growth of individual salmonids have been produced by poisoning feeder streams to reduce the numbers of juveniles entering lakes (Walker, 1975). Similarly numbers of lakes have been reclaimed for use for fisheries by removing vegetation with herbicides. Semi-biological activities, for example, aeration of water to improve its quality, or nutrient enrichment by sewage discharge are described in detail by Dunst et al., (1974).

Purely mechanical devices may be used to modify the nature of waterways to favour some aspect of the biology of a chosen species. Such activities as dredging and shoreline alteration in lakes or installation of deflectors and artificial cover in streams (Lagler, 1956) have been tried with varying degrees of success. They are usually designed to favour one particular species, and may even be detrimental to the fish stock as a whole. They are expensive, generally need constant attention and can probably only be justified in the case of species of high commercial value. This type of activity probably reaches its peak where the intervention is itself adapted as a fishing method as in the case of brush parks of the Grand Lac (Fily and d'Aubenton, 1966) or the fish holes of Dahomey (Welcomme, 1971). One related problem that has received considerable attention recently has been whether or not to clear brush from reservoirs prior to their being filled (Lagler, 1969). Programmes of brush clearances facilitate fishing but are expensive and may reduce productivity by reducing the living space for attached and burrowing organisms. In some cases these programmes have had unlooked for side effects on human health, e.g., proliferation of snail hosts of bilharsia in the cleared areas.

6.3 Stocking and Introduction of New Species

The planting of fish into an aquatic system from outside is a useful measure especially for the management of small or seasonal bodies of water. The main purpose is to supplement or replace recruitment by natural reproduction. In fisheries where exploitation is particularly intense the brood stock may become so reduced in number that almost the entire catch from the fishery depends on fish originating outside the system. There is thus, a good and well established correlation between stocking rates and catch per angler in heavily fished waters where stocks are frequently maintained at levels above the natural carrying capacity of the system. The most extreme example of this type of stocking is where turnover of individuals is generally very rapid and there is no natural reproduction. The stocking of small reservoirs and lakes is also widespread although here the optimum number of fish to be stocked per unit area depends ultimately on the natural conditions of productivity, growth and mortality in the water body concerned, as well as the amount of supplemental fertilisation or feeding undertaken. It is especially suitable where nearly complete harvesting is possible, as for instance in small seasonal reservoirs. In other waters, where natural reproduction is, on average, adequate to maintain stocks over the long-term, large year to year fluctuations in recruitment are often harmful to fishery development. The continuous stocking of large lakes and reservoirs, as for example practised in China, seem to be primarily to stabilise annual production.

The construction of dams on many water courses has stopped migratory fish reaching their habitual breeding grounds. Artificial fertilization, rearing and stocking of fry either upstream or downstream of the obstacle has enabled stocks of fish to be maintained in circumstances where they would otherwise have disappeared. Rice fields or other areas which dry up periodically can through repeated stocking also harbour stocks of fish during the wet phase which are captured as the system dries out.

Recently the possibility of poisoning existing populations out of small bodies of water in order to reconstruct artificially balanced communities has been proposed as a means of obtaining optimum output. Similarly, the creation of stocks of desirable species by planting is a common practice especially in Asian waters. Here reservoirs are seeded with various species of large cyprinids which are collected as fry in river systems. The fish species used do not normally breed in the lacustrine environment and sustained repeated stocking programmes are needed to maintain such fisheries. In this instance species which would naturally colonise the lacustrine habitats are rare because of the scarcity of lakes in the area.

While stocking to maintain fish populations is undoubtedly effective in such situations it is usually not economical in larger bodies of water where natural reproduction of an adequate variety of species occurs. In fact it is often forgotten that the natural productivity of a system cannot be exceeded in the long-term without artificial inputs of nutrients. As a result stocking is frequently advocated as a cure for overfishing, or stock depletion in situations where it is clearly inapplicable. Furthermore, in large rivers and lakes the balancing of numbers stocked against natural mortality between stocking and capture calls for such excessive numbers of fish that the exercise becomes uneconomic.

There has been considerable controversy in North America on the economics of maintaining fisheries through stocking as opposed to the reconstruction of natural populations in lakes where these have been damaged. Until recently stockings have generally been thought of as a relatively simple matter of planting the appropriate species but, recent Canadian experiences indicate that this is not so. Attempts to re-establish locally extinct stocks in lakes have met with little success and it is suspected that because the genetic composition of the species, which leads to the formation of geographically distinct sub-stocks, is not correct, self sustaining populations are not being set up. Little is known of this aspect of stocking, however, and more research is needed to clarify it.

Where continuous restocking of large lakes and rivers is practised it is usually because the species to be stocked are either of exceptional value, as for certain sportfish, or do not require expensive high-protein food as fry or fingerlings. The latter, is the main

reason for the apparent success of large-scale stocking programmes in Asian fisheries.

Introductions of fish into areas of the world from which they have previously been absent is common for all of the major uses of fisheries. The list of aquatic organisms so transferred would occupy many pages (see: Jhingran and Gopalakrishnan, 1974, for species introduced for aquaculture; Walford and Wicklund, 1973, for anadromous organisms, and Vooren, 1972, for Europe), but certain species can be singled out as having been more generally selected for transplantation. These include the rainbow trout (Salmo gairdneri) (McCrimmon, 1971 and 1972) which has been widely distributed mainly for sporting purposes. The common carp (Cyprinus carpio) and Cichlids of the genus Tilapia (principally T. mossambica) (Atz, 1954) have been introduced throughout the tropical world for aquaculture. As previously mentioned, Gambusia affinis has been used for mosquito control in many countries.

Some species transfers have been made to fill vacant niches in new (man-made) or existing lakes, such as the transplanting of the pelagic Limnothrissa miodon from Lake Tanganyika into Lake Kariba (Bell-Cross and Bell-Cross, 1971) and Lake Kivu. The Chinese carps, silver, grass and bighead were introduced into Russian reservoirs to feed on phytoplankton and rooted vegetation (Nikolsky and Aliyev, 1976). Similarly, the introduction of Lates niloticus into Lake Kyoga inserted a major predator into a food web from which one had previously been absent (Worthington, 1973). Other transfers are conceivable where water quality changes have annihilated populations of oligotrophic adapted species and replacement with species preferring eutrophic conditions is appropriate.

Such introductions are matters of great controversy and the literature on African waters typifies the dispute (Fryer, 1972 and 1973; Stoneman et al., 1973; Jackson, 1973). Examples can be cited where the introduced species has had drastic and unexpected effects on the native species. Gambusia for instance is an inveterate consumer of fish eggs, the common carp can make life intolerable for other species by its habit of stirring up of muddy bottoms (Jackson, 1960). The Tilapia species introduced into Lake Victoria have displaced some of the native species through competition for nursery grounds (Welcomme, 1967). Arguments about the advisability of introducing species depend much upon which objectives are selected. Few introductions have reduced the overall catch of food fish from a water, and indeed many appear to have succeeded in their primary intention and actually improved it, but they can be accused of having ruined a biotope by supplanting native species. An example of the latter is the introduction of black bass (Micropterus salmoides) into Lake Patzcuaro, Mexico. While the quantity of fish harvested was perhaps increased, the total value has been drastically reduced owing to declining catches of the native, highly priced pescado blanco (Chirostoma estor). Objections to introductions therefore have been based largely on the grounds of conservation which is itself a valid objective for the management of fisheries.

In considering introductions it is advisable to proceed with caution. (Courtenay and Robins, 1973; Regier, 1968). It should first be determined whether the introduction is in fact necessary, all too often some enthusiast will council adding yet another element to an already complex and successful stock only on the basis that it has done well elsewhere. Prospective candidates for introduction should of preference come from adjacent waters or the same zoogeographical area. Fish species which interact successfully elsewhere will probably continue to do so in the environment to be stocked. Should stocking be decided on, thorough studies should be undertaken to determine the acceptability of the species and to ensure that no unforseen competition will occur. A possible, and often overlooked, source of side effects is the introduction of disease along with the stocked species, and for this reason an international convention is being anticipated to limit movements of fish and fish eggs. Indeed it is often thought convenient to introduce species which will not breed in the new environment, or whose breeding or range is limited by climatic factors. One reason for the success of trout stockings in the tropical uplands is because there are few native species in the trout zone and the trout cannot penetrate the lower altitude warmer waters. Even this procedure is not fail-safe, especially where large numbers of fish are artificially raised to substantial size and planted, as with the grass carp. Under these circumstances the development of mutant strains capable of natural reproduction is certainly possible, though unlikely.

Only after these steps should the actual transfer of species take place even though the intention is only to culture the subject species in ponds or aquaria.

6.4 Aquaculture

Fish rearing and fish capture are both approaches to the management of the aquatic resource. The distinction between the two is not as clear cut as is usually supposed, and the range of available practices grade into one another. At one end of the scale, capture fisheries may be supported by stockings with cultured fingerlings, at the other, fry captured in the wild may be intensively cultured in ponds. Which method or combination of methods is adopted in any situation will depend on the economic and social conditions at the place and time. However, as capture fisheries for wild stocks near their maximum potential yields, or even decline in favour of alternative uses of the aquatic resource, the importance of production of fish by husbandry will inevitably increase. The culture of fish and other aquatic organisms implies a greater degree of control over the production cycle and avoids many of the hazards associated with fishery of natural stocks subject to variables outside the control of fishermen. Conversely, much greater vigilance is required to avoid catastrophic losses, as by disease, overcrowding and other hazards of intense cultivation.

Aquaculture itself has a range of objectives, consistant with those quoted in section 9, listed as follows by the TAC Working Group on Aquaculture (1973):

a) Culture for food production

b) Culture to improve natural stocks through artificial recruitment and transplantation

c) Culture for the production of sport fish

d) Culture of bait for commercial fishing

e) Culture of ornamental fish

f) Culture for industrial or other similar purposes

Its practice is fairly atuned to social usage in the various areas of the world, and very different regional attitudes prevail with regard to the objectives and the methods used. In Europe and North America, aquaculture has commonly been for purposes other than simple food production, and even where culture for food has been practised this has been confined to the intensive rearing of species that are considered especially desirable. In developing countries, however, production is principally for direct human consumption. Even here local differences occur, for whilst the majority of fish produced by aquaculture comes from peasant pond culture in Asia (Table V) attempts to introduce similar practices into some African countries have had limited success so far.

Reliable statistics on the actual production and role of aquaculture are lacking, but Pillay (1973) estimates world production of finfish by aquaculture at about 3.6 million tons, of which perhaps two-thirds comes from inland or brackish waters (Table V).

TABLE V

Estimated World Production of Finfish through Aquaculture
(condensed from Pillay, 1973)

Continent	Production t x 1 000
Asia	3 287
Europe (including U.S.S.R. and Israel)	329
North America	40
Latin America	20
Africa	4
TOTAL	3 680

The potential is impossible to assess realistically as it depends on priorities for the use of land and water suitable for aquaculture. Present day aquaculture tends to take advantage of lands of marginal value to agriculture and the potential production from such areas has been variously assessed at between 15 million tons (President's Science Advisory Committee, 1967) and 40-50 million tons annually (Bardach and Ryther, 1968).

The term aquaculture is used to cover a variety of practices which range from an almost complete control over both the aquatic and biotic components of the culture system, to the stocking of lakes or reservoirs relying on the natural productivity of the water body stocked. These differences are often expressed in terms of intensity, for in general the more control exercised over the system, the more fish can be reared per unit area and the more intensive the practice. However, intensive aquaculture in ponds, raceways, cages or enclosures is very demanding in terms of water quality and quantity, in terms of industrially prepared feeds and in terms of disease control. The system therefore is applicable to a fairly narrow range of circumstances where the cultured species is of sufficient economic importance to justify the high cost involved. Slightly less intensive culture of selected fish species, where the natural productivity of the aquatic component is supplemented by locally available feeds, is more widespread. Extensive raising of fish by "free range" techniques is useful in many areas. This involves the intensive breeding and rearing of fry of the selected species which are later stocked into waters where they take advantage of the natural productivity to grow prior to cropping. Rice fields, lakes, reservoirs and temporary pools are typical of the environments so treated (see section 6.3).

Aquaculture may be combined with other activities. Joint rearing of fish with pigs, cattle or ducks is well known in some countries. Rice-cum-fish culture is widespread and is successful in areas where insecticide use is low. The raising of fish in ponds enriched by sewage or heated by coolant waters from power stations is being investigated. Equally of interest are the possibilities of integrating aquaculture with irrigation schemes, by raising fish in cages or enclosures placed in the main canals or by installing ponds as a part of the canal network.

With regard to other users of the aquatic resource aquaculture is intolerant of most forms of pollution. Therefore, if a zone is selected for aquaculture some form of safeguard is necessary to protect the station from possible effluents arising upstream. As intensive aquaculture can itself be a polluting and eutrophicating activity, the number of stations that can be sited on one water course are limited.

Uses of aquaculture coupled with capture fisheries are widespread. Young stages of migratory fish are artificially bred, reared and stocked where passage to their breeding grounds in rivers is obstructed. Similarly, young fish produced by aquaculture are stocked into many natural waters to maintain stocks of sport or food species. Capture fisheries may alternatively serve as a source of young fish which are stocked into ponds or enclosures or cages for rearing to commercial size.

The practice of aquaculture viz a vis capture fisheries depends on social, economic and ecological considerations. Many successful indigenous forms of extensive aquaculture, which take advantage of the habits of fish in the wild, already exist in many parts of the world. Such methods tend to be complementary benefitting both captive and wild stocks. However, some forms of aquaculture could by impounding portions of natural waters, deny free living fish access to breeding grounds and possibly be detrimental to the wild stocks.

6.5 Influencing the Social and Economic Environment

In many countries legislation is ineffective as the means of enforcing the regulations are lacking or the intervention of government has not been accepted in this context. In such cases effective management may require less direct means of control. Furthermore, developments at the level of the human community, tend to assure the integration of fisheries into the whole frame of local and regional development. Thus, if fishing intensity is too high, alternative occupations should be sought for some of the fishermen, perhaps through assistance in establishing the services needed to support the fishery (boat and gear construction, engine repairs, fish processing, etc.), or in unrelated occupations. Sometimes this process occurs on its own, as in the case of the best fishermen who accumulate capital as a result of their fishing success and are able to move on to more acceptable occupations (Scudder, personal communication). Loan schemes or other assistance may be a useful way of accelerating such trends.

Many potential fisheries remain unexploited due to their isolation. In such cases the best strategy for development is probably the provision of good roads and landing sites. Similarly the local unacceptability of fish or of some elements of the fish stock as a food in certain areas, limits the use of the inland fishery resource. In such cases the search for new products or markets can result in the eventual development of the resource.

In all cases at the community level, an understanding of the needs for control is essential to good regulation. Without such understanding laws are disregarded and the best efforts of the fishery manager are largely dissipated. Effective fishery extension is therefore one of the most important aspects of all in fisheries management, for in this way the fisherman himself can be encouraged to participate in the rational use of the stocks he exploits for his own as well as for the common good.

7. SUMMARY

The maintenance of a fish stock in any body of water depends on a variety of factors, many of which are external to the fishery or even to the aquatic system (as summarised in Fig.4). Given the increasing pressures on water for industrial, agricultural and domestic uses, as well as on fish stocks themselves for food sport or other purposes, a balance has to be maintained between the requirements for fisheries and those of other users.

This balance need not be difficult to agree upon, given appropriate organisation for the discussion and resolution of questions of overall objectives, but may nevertheless be difficult to achieve owing to still inadequate understanding of the functioning of such complex systems as lakes and rivers and their accompanying living communities. Nevertheless, some general principles appear to be emerging.

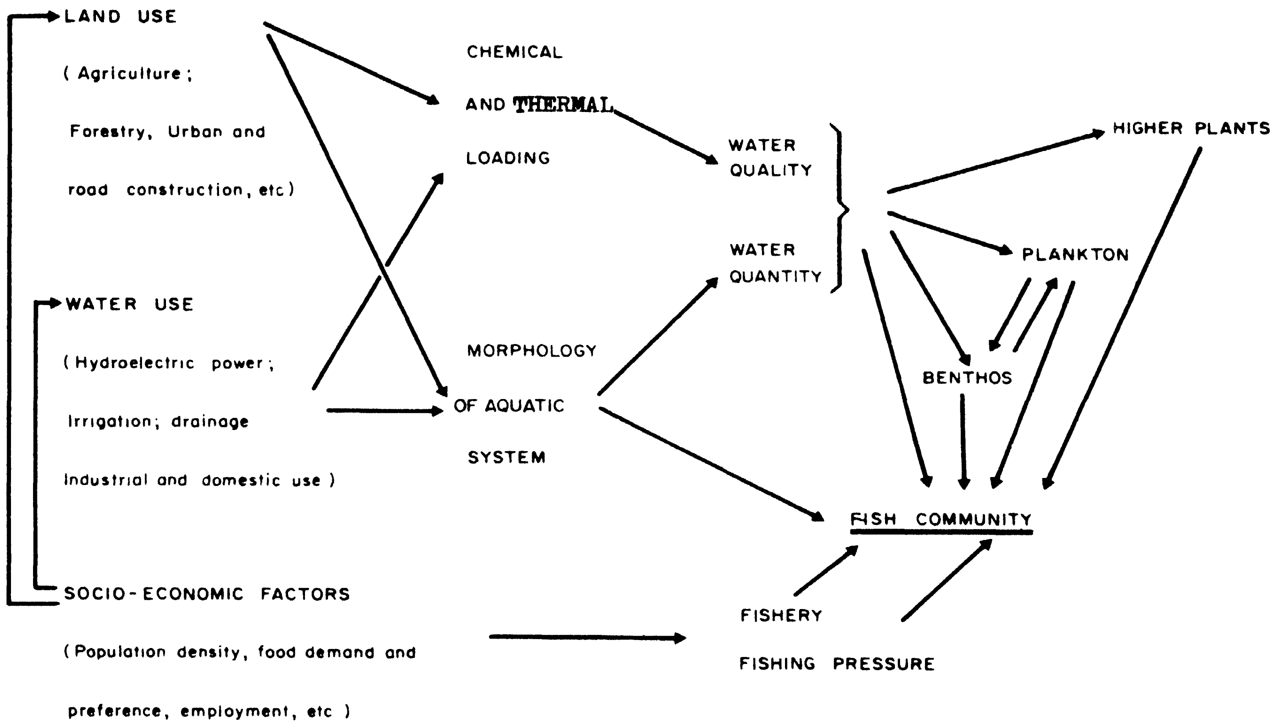


Figure 4 Diagram of relationships of various factors influencing inland fish communities

Fish communities appear to undergo similar changes when subject to loading whether it be from pollution, modification of the environment or fishing pressure. These involve a progressive displacement of the community towards the smaller, faster growing but shorter lived species. The more highly appreciated species both for food and for sport are usually those larger, slower growing ones which disappear early in this process.

Management of the aquatic system for fisheries under these conditions depends on two major policy levels. Firstly the importance of fisheries relative to other users of the river or lake basin, and secondly the objectives for the management of the fishery itself. The more the fishery objectives concentrate on the larger species the stricter the needs for control of both the fishery and other users of the water.

Fishery managers have a variety of tools which permit them to manipulate the fish community. These include legislation to control or direct fishing effort, modification or protection of the physical structure of the environment, culturing fish under more or less controlled conditions, stocking waters with externally produced fish or introduction of new elements to the community. However, these can only be successful if the physical environment is maintained in a condition that will permit the chosen elements of the community to flourish.

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